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# DIFFERENCES IN THE AGE AND GROWTH OF WHITE GRUNT (*HAEMULON PLUMIERI*) FROM NORTH CAROLINA AND SOUTH CAROLINA COMPARED WITH SOUTHEAST FLORIDA

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## ABSTRACT

White grunt, *Haemulon plumieri*, otoliths were collected from headboat and commercial fisheries in North Carolina and South Carolina ( $n = 607$ ), and southeast Florida ( $n = 634$ ). In addition, fishery-independent samples ( $n = 116$ ) were collected from North Carolina and South Carolina. White grunt from the two regions along the southeastern U.S. coast may be separate stocks and should be analyzed separately for management purposes. White grunt from the Carolinas were larger at age than white grunt from southeast Florida. Age and size ranges of Carolina fish were 1–13 yrs and 173–512 mm total length (TL). Age and size ranges of southeast Florida fish were 2–15 yrs and 192–360 mm TL. White grunt caught off the Carolinas by recreational anglers since 1981 have averaged 60 to 100 mm TL larger than those landed by recreational anglers fishing off southeast Florida. The von Bertalanffy growth curves for this species from the Carolinas and southeast Florida are  $L_{\infty} = 591(1 - e^{-0.08(t + 4.21)})$  and  $L_{\infty} = 327(1 - e^{-0.19(t + 4.21)})$ , respectively. The weight-length relationship of white grunt from North Carolina and South Carolina is  $W = 1.12 \times 10^{-5}(L)^{3.05}$  and from southeast Florida,  $W = 6.33 \times 10^{-5}(L)^{2.73}$ , where  $W$  = whole weight in g and  $L$  = TL in mm.

White grunt, *Haemulon plumieri*, are warm-temperate to tropical reef fish occurring in the eastern Atlantic from Virginia and Bermuda to Brazil including the Gulf of Mexico and Central America. White grunt and the congener tomtate (*Haemulon aurolineatum*) occupy the northernmost range of all haemulids (Gaut and Munro, 1983). White grunt are found on offshore hard bottom off North Carolina and South Carolina in waters warmed by the Gulf Stream, but remain in shallower waters off southern Florida (Darcy, 1983; Gaut and Munro, 1983).

The distribution of the white grunt population is disjunct along the southeastern United States. The species is abundant off North Carolina and South Carolina and Palm Beach County, Florida, through the Florida Keys, but it occurs infrequently off Georgia and northeast Florida [Linda Hardy, pers. comm., General Canvas Landings, Center for Coastal Fisheries and Habitat Research, 101 Pivers Island Road, Beaufort, North Carolina 28516; Robert Dixon, pers. comm., Headboat Survey, Center for Coastal Fisheries and Habitat Research, 101 Pivers Island Road, Beaufort, North Carolina 28516]. Differences in mean size of this species from the two areas have been noted by port samplers of the National Marine Fisheries Service and by fishermen. Based on headboat data from 1981–1997, the mean size of white grunt from the Carolinas has held steady at 331 mm total length (TL) (586 g); while the mean size of southeast Florida white grunt was 270 mm TL (289 g) for the same time period, again with no change over the 16 yrs of sampling. The Marine Recreational Fishery Statistical Survey (MRFSS) [National Marine Fisheries Service, 1331 East-West Hwy., Silver Spring, Maryland 20910] data from 1981–1997 and the Trip Interview Program [TIP Database, Joshua Bennett, National Marine Fisheries Service, Miami Laboratory, 75 Virginia Beach Drive, Miami, Florida 33149] (commercial samples) data from 1990–1997 indicated a similar trend in mean size of white grunt from both

areas: 360 mm TL from the Carolinas and 248 mm TL from southeast Florida, and 363 mm TL from the Carolinas and 276 mm TL from Florida, respectively. An age and growth study of white grunt from Puerto Rico and the Virgin Islands indicated that the species was considerably smaller in the Caribbean compared with those caught off the Carolinas (Sadovy et al., 1989).

The suggestion of separate stocks of white grunt along the southeastern U.S. due to its distribution and size differences, lead to a genetic study of white grunt. Chapman et al. (1999) have found three distinct genetic lineages of white grunt based on mitochondrial DNA. Two of the forms were found in the southeastern U.S. The 'Carolinian' was found from North Carolina through the Florida Keys and into the Gulf of Mexico. The 'Caribbean' mixes with the Carolinian in the Florida Keys and is the dominant one (75%). Because of the mixing of the two genetic forms in south Florida, data analysis of the species from that area may be difficult.

Other biological information on white grunt from the southeastern U.S. is scarce. The only published age and growth study of the white grunt from the southeastern U.S. is by Manooch (1976). He used scales and otoliths collected from the North Carolina and South Carolina headboat landings, and used data from scales to estimate back-calculated lengths and theoretical growth. A South Carolina Department of Natural Resources (SCDNR) Marine Resources Monitoring and Predication (MARMAP) Program age and growth study used otoliths from fish caught by fishery-independent and commercial operations from North Carolina and South Carolina (Padgett et al., 1997). In addition, an age and growth study of white grunt from the northwest coast of Florida is in progress [Debra Murie, pers. comm. University of Florida, Department of Fisheries and Aquatic Sciences, 7922 NW 71<sup>st</sup> Street, Gainesville, Florida 32653-3071]. Our study is the only study we are aware of that examines age and growth of the species from southern Florida.

Because of the disparity in mean size of white grunts landed in the Carolinas compared to those landed in southeast Florida, we will describe the sizes-at-ages, back-calculated and theoretical growth, weight-length relationships, and age-length keys for white grunt by the separate areas. The differences between the two stocks may be enough to impact stock assessments of the species and resulting management, such as minimum size limits.

## METHODS

Sagittal otoliths were collected dockside from white grunt landed by hook-and-line fishermen from the headboat (recreational) fishery and the commercial fishery operating in two areas of the southeastern U.S. during 1990–1998: (1) North Carolina and South Carolina ( $n = 555$  headboat and  $n = 52$  commercial; and (2) Palm Beach County, Florida, through the Florida Keys ( $n = 269$  headboat and  $n = 365$  commercial). In order to obtain otoliths from smaller fish than those collected from fishery-dependent gear off North Carolina and South Carolina, SCDNR's MARMAP Program, a fishery-independent sampling program, made white grunt samples ( $n = 116$ ) available for this study. No fishery-independent samples were available from southeast Florida. Total length, whole weight, area of capture, and date of capture were recorded for each sample. Sex of the fish was not recorded. The otoliths were stored dry in coin envelopes.

For age analysis, three transverse (dorsoventral) sections were taken from the left otolith of each fish sampled using a low-speed saw. One section was made on either side of the core, and the other encompassed the core. Sections were mounted on glass slides with a thermal cement, and both authors independently examined the sections through a stereo microscope with reflected light at 80 $\times$ . Clove oil was applied to each section to enhance the readability of the zones on the section.

Measurements from the core to the outer edge of each successive opaque zone and the otolith margin (marginal increment) were taken along the lateral plane on the dorsal lobe of the section.

Marginal increment analysis was used to validate the opaque zones as annuli. The mean marginal increment by month was plotted along with the percent of fish with a marginal increment equal to zero. If the opaque zones were formed once each year, then the plot should reveal a minimum zone-to-margin increment followed by increased increment width.

Back-calculated total lengths were estimated from the fish length and otolith radius relationship. The linear regression equation was  $L = a + b(R_C)$ , where  $L$  = total length in mm and  $R_C$  = otolith radius in ocular micrometer units. The back-calculated lengths at each age were determined from the body proportional equation (Francis, 1990):

$$L_A = \left[ \frac{a + bR_A}{a + bR_C} \right] * L_C,$$

where  $L_A$  = Back-calculated length to annulus A,  $a$  = intercept from the linear total length-otolith radius regression,  $b$  = slope from the linear total length-otolith radius regression,  $L_C$  = total length at time of capture,  $R_A$  = otolith radius to annulus A, and  $R_C$  = total otolith radius at time of capture.

Next, theoretical growth of white grunt was estimated. The von Bertalanffy equation:  $L_t = L_\infty [1 - \exp(-K(t-t_0))]$ , was fit to back-calculated length-at-age data at the most recent annulus (Ricker, 1975; Everhart et al., 1981; Vaughan and Burton, 1994). Growth parameters were estimated using SAS PROC NLIN with the Marquardt Option (SAS Institute, 1982). To further describe the growth pattern of white grunt, the  $\ln$ - $\ln$  regression of fish weight on fish length was performed and transformed to  $W = a(L)^b$ , where  $W$  = weight in g, and  $L$  = total length in mm.

Differences in mean age at size for the two geographic regions were tested using analysis of variance [ $\text{age} = a + b(L)$ , where  $L$  = total length in mm]. The test was conducted on the most recent back-calculated lengths at age on age by region so that all the sizes of the fish were standardized.

An age-length key was constructed based on observed age at length in which the ages were not adjusted for time of year. The samples spanned all months of the year and corresponded to fishing effort. The aged fish were assigned to 25 mm length classes. Age distribution (shown as number of fish) was identified for each size interval.

## RESULTS

Sectioned sagittal otoliths were examined to determine ages for white grunt. The opaque zones on the otoliths were more legible on the sections than on the whole otoliths due to the thickness of it. Of the 723 otoliths from white grunt landed in North Carolina and South Carolina, 720 (99%) were assigned ages ranging from 1–13 yrs (173–512 mm TL) (Table 1). Of the 634 otoliths from white grunt landed in southeast Florida, 618 (98%) were assigned ages ranging from 2–15 yrs (192–360 mm TL) (Table 2). Differences in the age range versus the size range of white grunt captured in the two geographical regions were statistically different using ANOVA performed on the most-recent back-calculated lengths ( $F = 61.29$ ;  $P < 0.05$ ) for all ages. For this reason, the rest of the analysis will be conducted on the two areas separately.

We validated the opaque zones as annuli using marginal-increment analysis. White grunt from North Carolina and South Carolina deposit an annulus in March and April (Fig. 1A), which corresponds to the onset of spawning in this region (Padgett et al., 1997). Manooch (1976) and Padgett et al. (1997) also reported the formation of the annulus in March and April. In southeast Florida, deposition of the opaque zone occurred from March

Table 1. Mean observed and back-calculated total lengths at age of white grunt from North Carolina and South Carolina based on the Francis body proportional hypothesis.

Age	Observed Mean TL	n	Annulus												
			1	2	3	4	5	6	7	8	9	10	11	12	13
1	197	3	137												
2	218	38	131	197											
3	280	79	135	210	259										
4	314	184	136	210	261	300									
5	339	96	132	206	254	293	322								
6	364	93	134	208	259	297	326	350							
7	374	68	130	203	251	288	316	341	360						
8	390	57	129	203	252	288	317	342	363	380					
9	400	25	127	198	248	286	315	338	359	376	390				
10	417	11	122	194	240	277	307	334	356	375	390	405			
11	412	5	125	195	242	276	308	335	359	378	393	406	417		
12	436	4	123	196	238	276	304	330	351	370	381	392	406	417	
13	481	1	107	207	261	301	341	374	401	414	428	441	454	461	468
Weighted Mean TL			133	206	256	294	320	344	361	378	391	404	416	426	468
Increment				73	50	38	26	24	17	17	13	13	12	10	42

through June with a peak in May (Fig. 1B), which corresponds with peak spawning for that area (Moe, 1966; Gaut and Munro, 1983).

Fish somatic growth to otolith growth was linear but more highly correlated for North Carolina–South Carolina data than for Florida data. The linear relationship of total length to otolith radius for white grunt from North Carolina and South Carolina is represented by the equation:  $L = -6.72 + 7.01(R_o)$  ( $n = 713$ ;  $r^2 = 0.85$ ; SE of intercept and slope are 5.50 and 0.11, respectively). In contrast, the linear relationship for Florida data is best represented by the equation:  $L = 62.0 + 4.77(R_o)$  ( $n = 617$ ;  $r^2 = 0.51$ ; SE of intercept and slope are 8.14 and 0.19, respectively). The mean back-calculated lengths at the most recent annulus formed for ages 2, 5, and 10 of white grunt from North Carolina and South Carolina were 197, 322, and 405 mm (Table 1) compared to 218, 274, and 288 mm TL for white grunt from southeast Florida (Table 2).

We estimated the von Bertalanffy growth curves using the back-calculated lengths at the most recently formed annulus. Because there were so many white grunt collected from North Carolina and South Carolina in the mid-size range (250–400 mm TL), we weighted the equation based on the inverse of the sample size at each age to give more weight to the few older fish. The resulting growth equation is  $L_t = 591(1 - e^{-0.08(t+4.21)})$ , asymptotic  $SE_{L_\infty} = 38.39$ ,  $SE_K = 0.02$ , and  $SE_{t_0} = 0.80$  (Fig. 2A). The curve we report slightly over-estimates theoretical lengths for age 1 and 2 fish as compared to the back-calculated lengths due to the weighting scheme we used, in order to not underestimate the lengths of the older fish (Fig. 2A). The von Bertalanffy growth curve for white grunt from southeast Florida using the inverse weighting scheme is  $L_t = 327(1 - e^{-0.19(t+4.21)})$ , asymptotic  $SE_{L_\infty} = 3.12$ ,  $SE_K = 0.02$ , and  $SE_{t_0} = 0.67$  (Fig. 2B).

Another equation important to estimating fish growth is the weight-length relationship. For white grunt landed in North Carolina and South Carolina by headboat fishermen from 1981–1998, the relationship is best described by  $\ln(W) = -11.41 + 3.05\ln(L)$ , where  $W$  = whole weight in g and  $L$  = total length in mm ( $n = 24,715$ ,  $r^2 = 0.91$ ,  $MSE = 0.026$ , SE is 0.04 and 0.01 for intercept and slope, respectively). The transformed equa-

Table 2. Mean observed and back-calculated total lengths at age of white grunt from southeast Florida based on the Francis body proportional hypothesis.

Age	Observed Mean TL	n	Annulus														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2	236	13	162	218													
3	250	199	157	208	240												
4	270	176	158	208	239	262											
5	282	83	157	208	238	258	274										
6	290	44	158	208	237	259	274	285									
7	301	26	158	209	238	259	274	286	296								
8	297	14	155	206	236	255	265	280	289	297							
9	307	10	151	202	230	249	263	275	285	295	302						
10	292	3	154	195	219	234	246	256	265	274	283	288					
14	320	1	158	209	241	260	269	278	288	292	297	301	306	311	315	320	
15	322	1	150	204	236	254	268	277	286	290	295	299	304	308	313	317	322
Weighted Mean TL			157	208	239	260	272	282	290	293	297	293	305	310	314	319	322
Increment				51	31	21	12	10	8	3	4	*	12	5	4	5	3

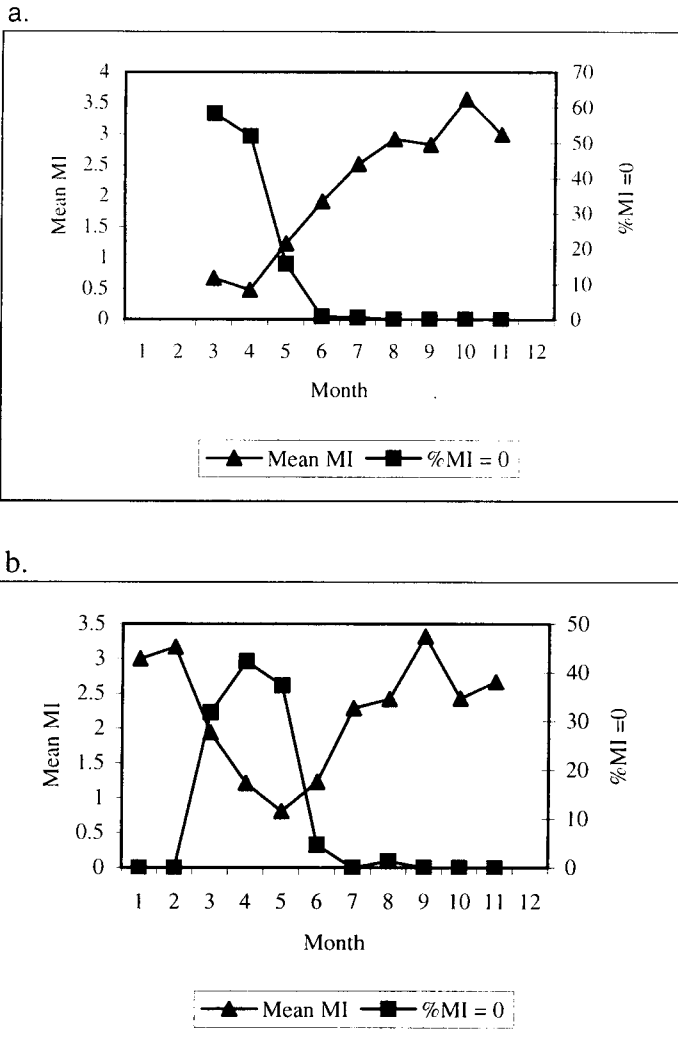


Figure 1. Marginal increment analysis of white grunt from the southeastern United States: a. North Carolina and South Carolina; b. southeast Florida. (%MI = 0 is the percent of measured marginal increments being equal to zero.)

tion is  $W = 1.12 \times 10^{-5}(L)^{3.05}$ . Our equation is similar to the one given by Manooch (1976) and those listed by Padgett et al. (1997). White grunt from southeast Florida are lighter at size than are those from North Carolina and South Carolina. The weight-length relationship for this species from southeast Florida based on headboat data from 1981–1998 is  $\ln(W) = -9.68 + 2.73\ln(L)$  ( $n = 26,882$ ,  $r^2 = 0.77$ ,  $MSE = 0.03$ , with an SE of 0.05 and 0.01 for intercept and slope, respectively). The transformed equation is  $W = 6.3 \times 10^{-5}(L)^{2.73}$ . The slope of the weight-length curve was skewed by the large number of small fish in the samples available for aging and did not accurately predict the weights for the larger fish.

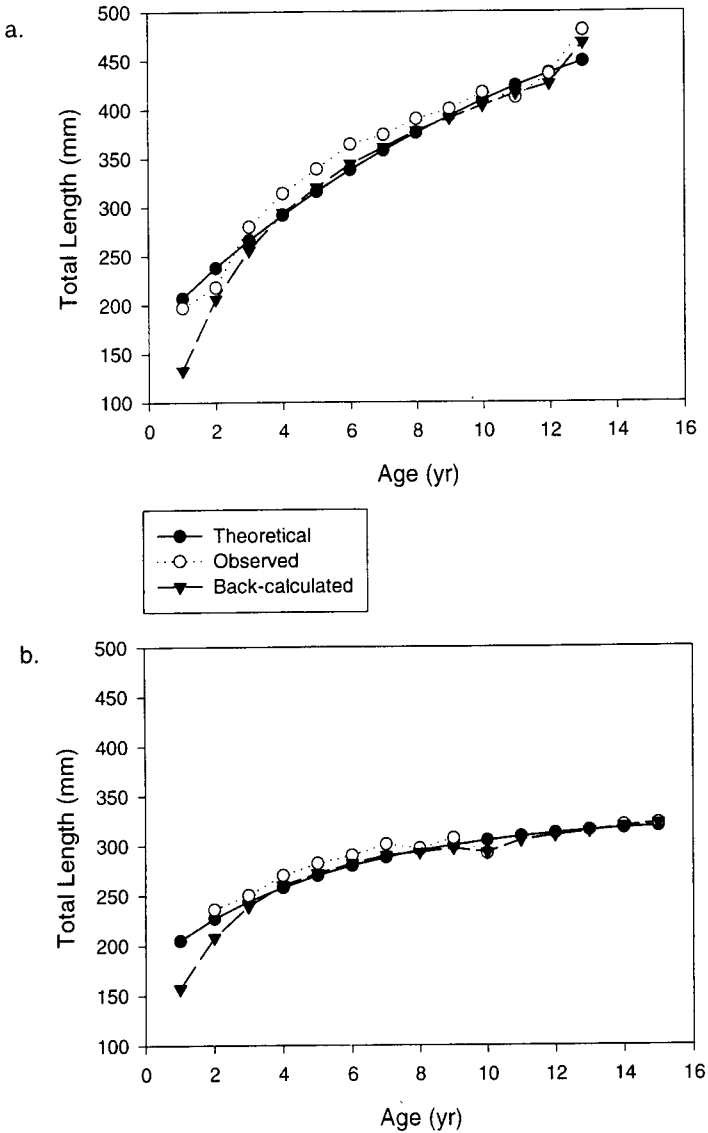


Figure 2. Mean observed, back-calculated, and theoretical total lengths of white grunt: a. North Carolina and South Carolina; b. southeast Florida.

Age-length keys for white grunt from the Carolinas and from southeast Florida are presented in Tables 3 and 4, respectively. The two keys were developed for all fisheries combined, partly due to small sample sizes of the three fisheries in the Carolinas that precluded stratification of the data. The age-length keys can be used in conjunction with length frequency data from the fisheries to construct catch-at-age, and subsequently, estimate total mortality,  $Z$ , for stock assessment purposes.



Table 3. Age-length key of white grunt from North Carolina and South Carolina. Total length class is 25 mm intervals (i.e., 175–199, 200–224, etc).

Size	Age group (year)												
TL (mm)	1	2	3	4	5	6	7	8	9	10	11	12	13
150	1												
175		14											
200	2	7											
225		14	7	1									
250		4	33	10									
275			28	46	9	2							
300			16	73	23	6	3	2					
325			1	46	39	22	14	13			1		
350				19	28	28	23	8	6	1	1		
375				1	11	29	18	14	6	2		1	
400					1	9	10	15	7	6	2	1	
425							7	9	4	2	1	1	
450								4	2			2	
475								1					1
500										1	1		
n	3	39	85	196	111	96	75	66	25	12	6	5	1

## DISCUSSION

We feel that white grunt from the two regions along the southeastern U.S. coast are separate stocks and should be analyzed separately for management purposes. White grunt from southeast Florida grow much slower and do not attain the size of specimens found in the waters off North Carolina and South Carolina. It is unclear whether the differences are due to the mixing of distinct genetic forms in south Florida, or whether much greater fishing pressure and increased accessibility in south Florida (the fishing grounds are as close as 3 mi compared to 30 mi offshore in the Carolinas) has somehow altered the growth characteristics of the species. However, if we were to apply growth characteristics of white grunt from the Carolinas to southeast Florida data, the spawning potential ratio (SPR) values could be under-estimated. Thus, the population would be considered over-

Table 4. Age-length key of white grunt from southeast Florida. Total length class is 25 mm intervals (i.e., 175–199, 200–224, etc).

Size	Age Group (year)										
TL, mm	2	3	4	5	6	7	8	9	10	14	15
175		1									
200	3	21	6								
225	7	79	29	6	1		1				
250	3	80	73	29	14	1	1				
275		22	64	41	21	11	5	6	3		
300		2	23	15	11	12	7	3	1	1	1
325				2	6	2	1	1			
350				1				1			
n	13	205	195	94	53	26	15	11	4	1	1

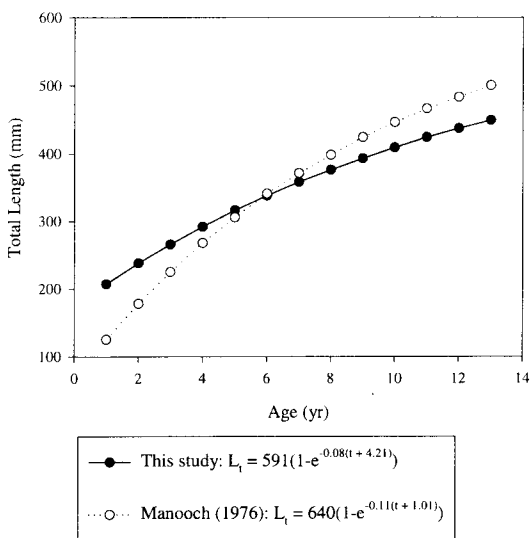


Figure 3. Comparison of von Bertalanffy growth curves for white grunt from North Carolina and South Carolina from this study and Manooch (1976).

fished because the southeastern Florida grunts would not attain the larger sizes or total mortality level predicted. In that case, fishing mortality would be over-estimated. The opposite could occur if southeast Florida age and growth results were applied to Carolinas fish. Also, based on our analyses, it would be inappropriate for a management agency to apply the same regulation, such as minimum size limit, for white grunt for the entire U.S. southeastern coastal region. White grunt from southeast Florida only grow to two-thirds the size of white grunts from the Carolinas.

Assigning ages to white grunt from otoliths was not difficult and was validated through marginal-increment analysis. Furthermore, for the white grunt from southeast Florida, the mean back-calculated length at age 1 (157 mm TL) was very close to the estimated size of age 1 white grunt collected from Florida Bay (127 mm TL,  $n = 21$ ), as determined from daily increment counts [Lawrence Settle, pers. comm., NOAA, Center for Coastal Habitat and Fisheries Research, 101 Pivers Island Road., Beaufort, North Carolina 28516-9722].

White grunt age structure and growth from North Carolina and South Carolina do not seem to have changed over the past 20+ yrs. Manooch (1976) reported the maximum age from scales was 13 yrs with a mean TL of 526 mm ( $n = 6$ ), compared to a fish 512 mm TL and a maximum age of 13 yrs for this study. The most frequently encountered age in Manooch's study was three, ranging in size from 225–325 mm TL. Our age 3's ranged in size from 237–328 mm TL. The most frequently encountered age in our study was four. Both studies had few fish older than 9 yrs. Because the data used to derive the growth curve for this study are from several fisheries and gear types and are from recent years' collection, we feel that this curve more accurately depicts the growth of the current Carolina population than that reported by Manooch (1976). However, our equation is comparable to the one estimated by Manooch (1976):  $L_t = 640(1 - e^{-0.11(t+1.01)})$ . The differences in the plots of the theoretical length curves (Fig. 3) are partly due to the different methods

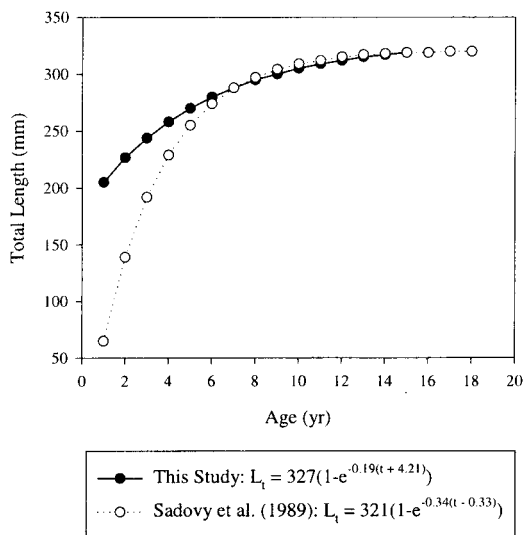


Figure 4. Comparison of von Bertalanffy growth curves for white grunt from southeast Florida (this study) and from Puerto Rico (Sadovy et al., 1989).

used in estimating the parameters. For example, Manooch (1976) used the straight regression equation while we used the body proportional equation to derive the back-calculated lengths; Manooch also used back-calculated lengths at all annuli compared to our method of only using the most recently formed annuli; there was no weighting scheme compared to our inverse weighting scheme.

Although, the results of this study are similar to Manooch (1976), the age and growth detailed in Padgett et al. (1997) are very different. Padgett et al. (1997) found white grunt as old as 27 yrs (459 mm TL;  $n = 1$ ), though 95% of the samples were between ages 1 and 8. The fishery-independent (MARMAP) caught white grunt were slower growing than the commercially caught white grunt, which was reflected in the von Bertalanffy growth equation, but 23% of our samples were larger than three of the four  $L_{\infty}$ s reported (Padgett et al. 1997). We have no explanation for the drastic differences in results between this study and Padgett et al. (1997) other than the possibility of reader error, gear selectivity, or faster growing fish recruiting to the fishery first.

Differences in the age-structure and growth patterns of white grunt from the Carolinas and southeast Florida have clearly been illustrated in this study. The largest fish sampled in southeast Florida was 360 mm TL, but ages ranged up to 15 yrs. Moe (1967) noted a marked decrease in growth rate of this species off the central west coast of Florida after a size of 200 mm FL (~230 mm TL). Our findings are similar to Moe's observation in that white grunt from southeast Florida only grew 96 mm TL from age 2 to age 15 (based on observed mean lengths at age). Randall (1962) also reported very slow growth of white grunt from the Virgin Islands, which was similar to growth reported by Sadovy et al. (1989) for white grunt from Puerto Rico and the Virgin Islands. There, the species only grew 105 mm TL between age 2 and age 15. The growth equation estimated by Sadovy et al. (1989) from white grunt landed in Puerto Rico and the U.S. Virgin Islands is similar to ours for ages 6 through 15:  $L_t = 321(1 - e^{-0.34(t-0.33)})$ . Again, the difference in the plots,

especially for ages 1 through 5, is due to the methods used to estimate parameters, in particular the weighting scheme we used (Fig. 4). We feel that the theoretical lengths for the younger ages were under-estimated by Sadovy et al. (1989), while ours are slightly over-estimated for age 1 and 2 fish compared to our back-calculated lengths (Fig. 2B).

In conclusion, we believe this study was comprehensive for the southeastern U.S. and can be used by managers for stock assessment purposes. More investigation needs to be made into the reasons for the differences in age and size range between the Carolinas white grunt and southeast Florida white grunt.

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